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Behaviour of electrical steels under rotationnal magnetization and high temperatures

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1. INTRODUCTION

Context

- Increasing environmental concerns
- Raise in design requirement for electrical devices
- Need for... better modelling of magnetic cores
- ...improved models
- ...adequate engineering data (to establish and apply models)

Problematique

- Motors & transformers cores...
- ...work at elevated temperatures
- ...are the sites of two-dimensional fields
- Adequate engineering data can be both
 - Temperature dependant
 - Two-dimensional (2D)

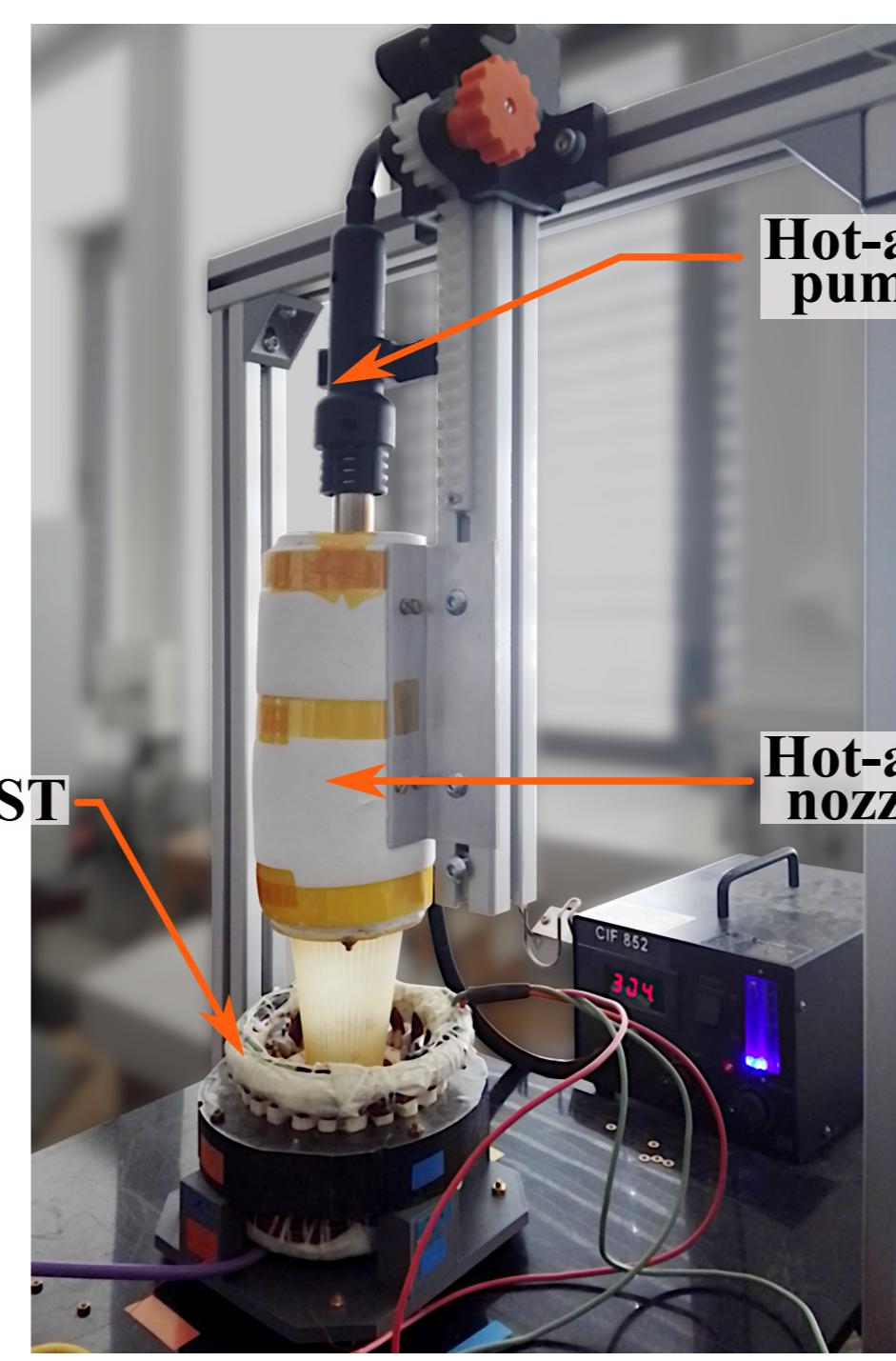
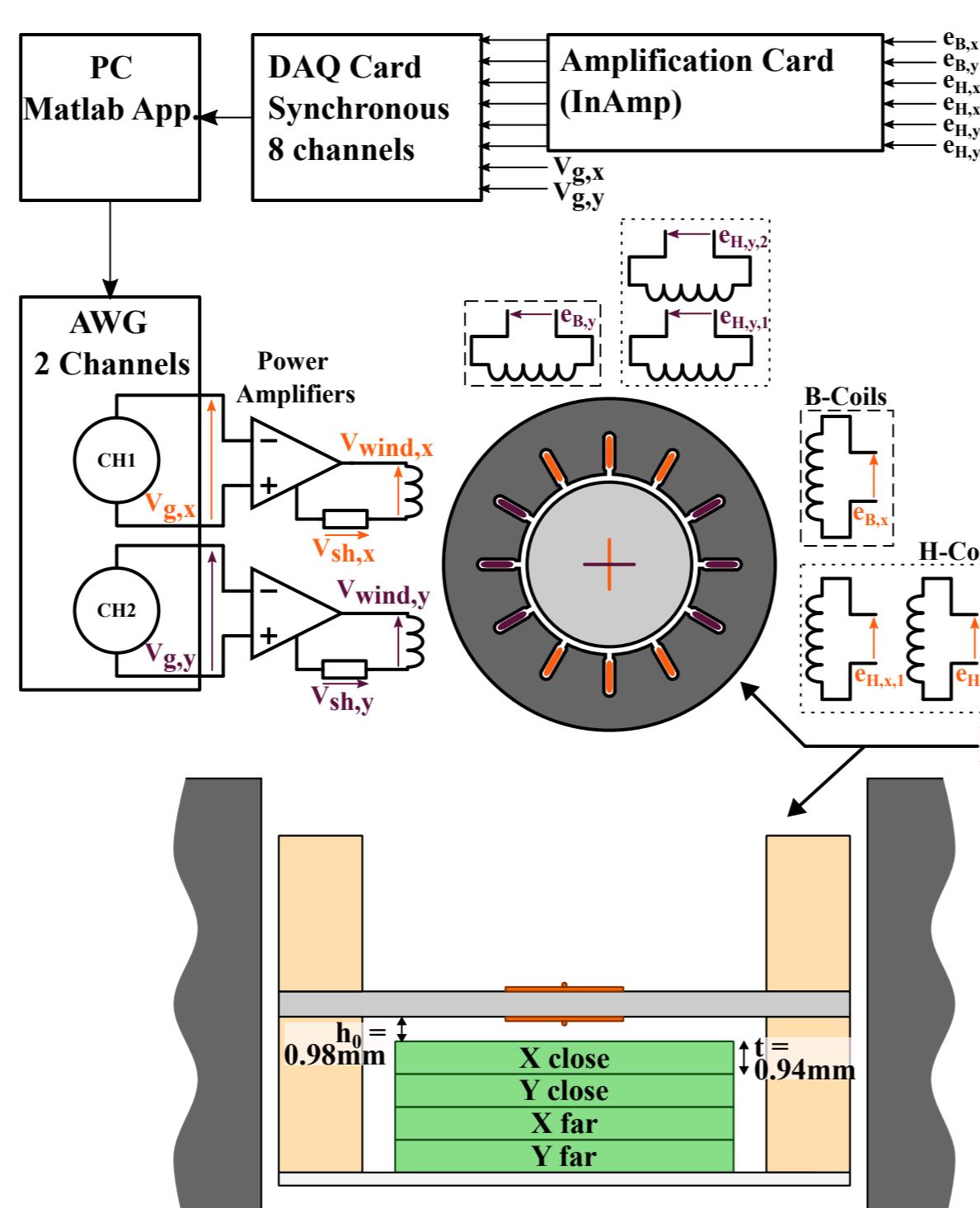
Proposed work

- 2D Caractérisations of electrical steel samples (NO & GO) for different temperatures
 - For a few frequencies
 - For various induction levels
- Comparaison avec 1D temperature behaviour
 - NO only

2. EXPERIMENTAL SETUP

Rotationnal Sheet Tester (RSST)

- Stator-based (2 phases)
- Sensors : all coils
 - B: through holes
 - H: tangential flat coils + linear extrapolation
- Capabilities
 - $f \in [5,200]$ Hz
 - $H \in [50,7500]$ A/m (roughly)

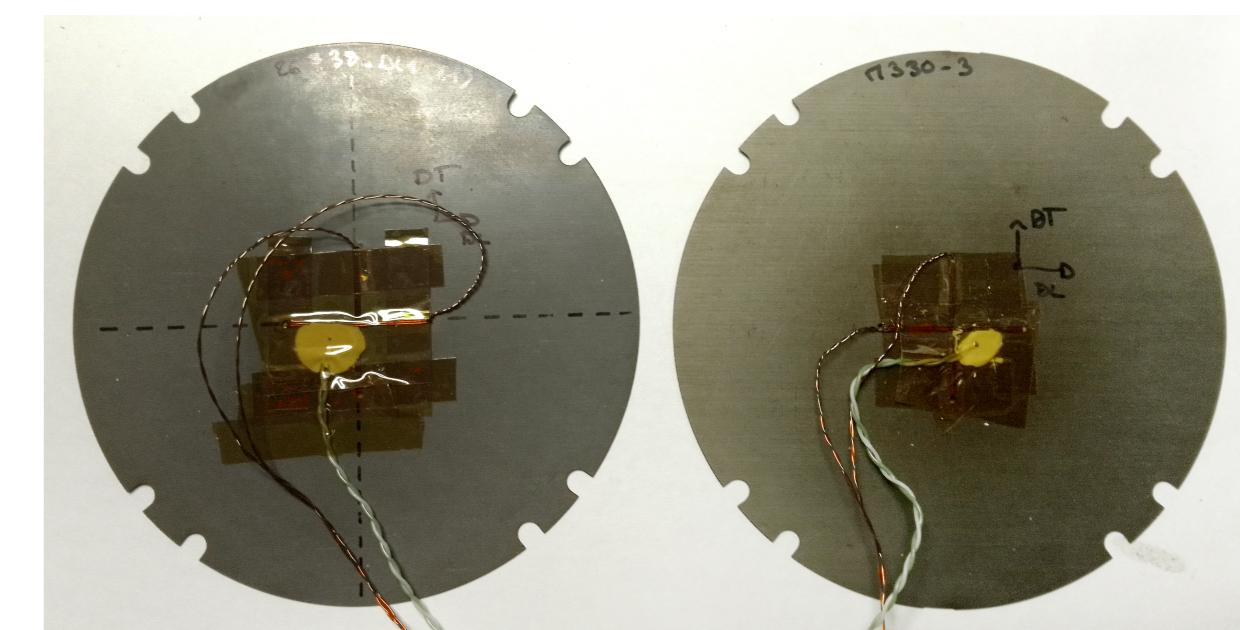


Temperature control

- Heating by flowing hot air over the sample
- Open Loop
- Measurement: thermocouple
- Capabilities
 - $T_{sample} \in [50,250]$ °C (from $T_{air} \in [200,400]$ °C)
 - Transient state ≈ 3 h

3. STUDY CONDITIONS

Samples

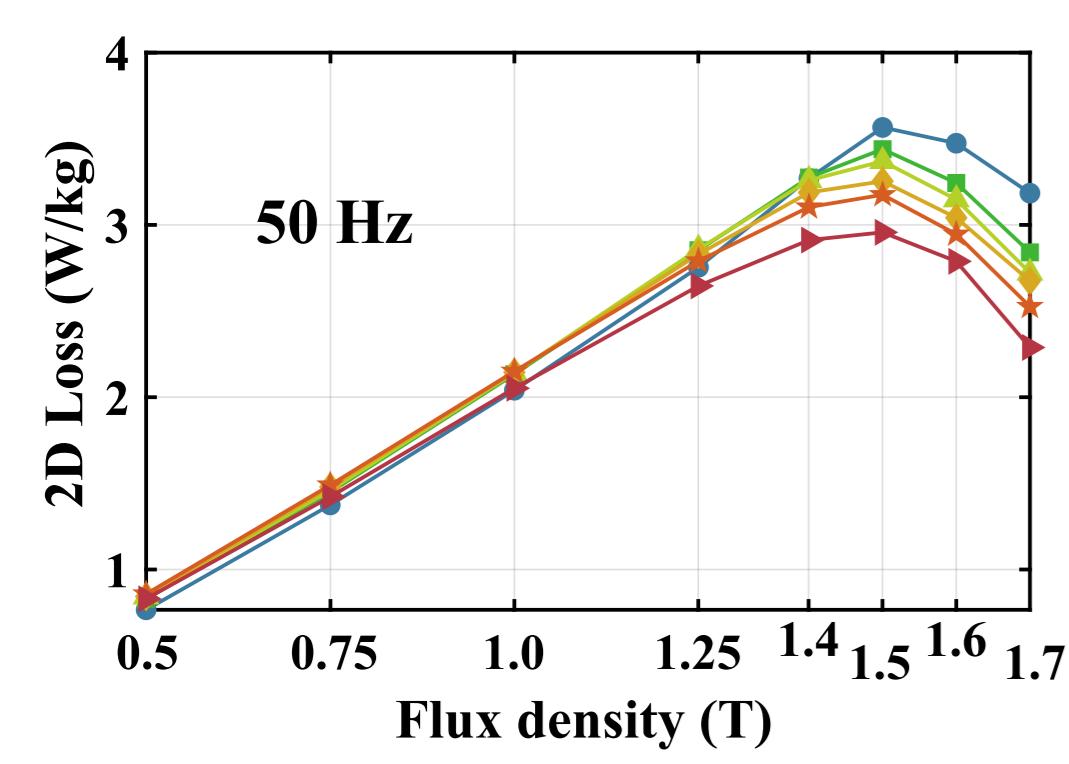


Grain-Oriented	FeSi	Non-Oriented
0.23 mm	Thickness	0.33 mm
2.03 T	J_{sat}	≈ 1.7 T
$\approx 700-800$ °C	T_{curie}	745 °C
0.5-1.7 T	Achieved B_{peak}	0.5-1.15 T

Studied physical quantities

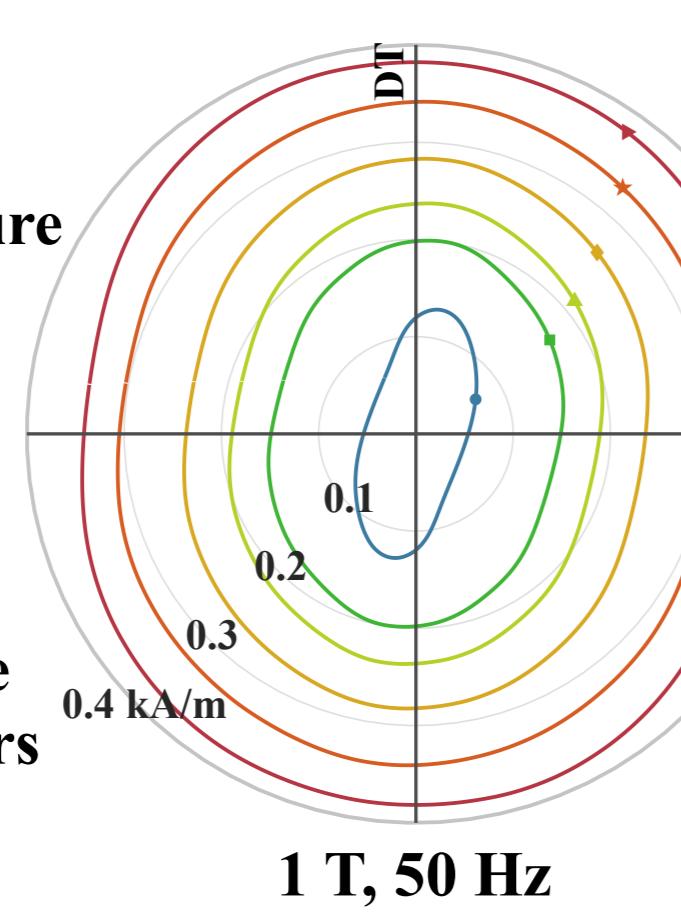
- Loss & H-loci under controlled circular flux density
- NO : From linear to saturated region
- GO : For low flux-densities only (limitations in apparent power & control)
- Measurements for 10, 50 & 100 Hz
- Low changes in temperature behaviour over this frequency range
- Only 50 Hz results shown here

4a. NO 2D



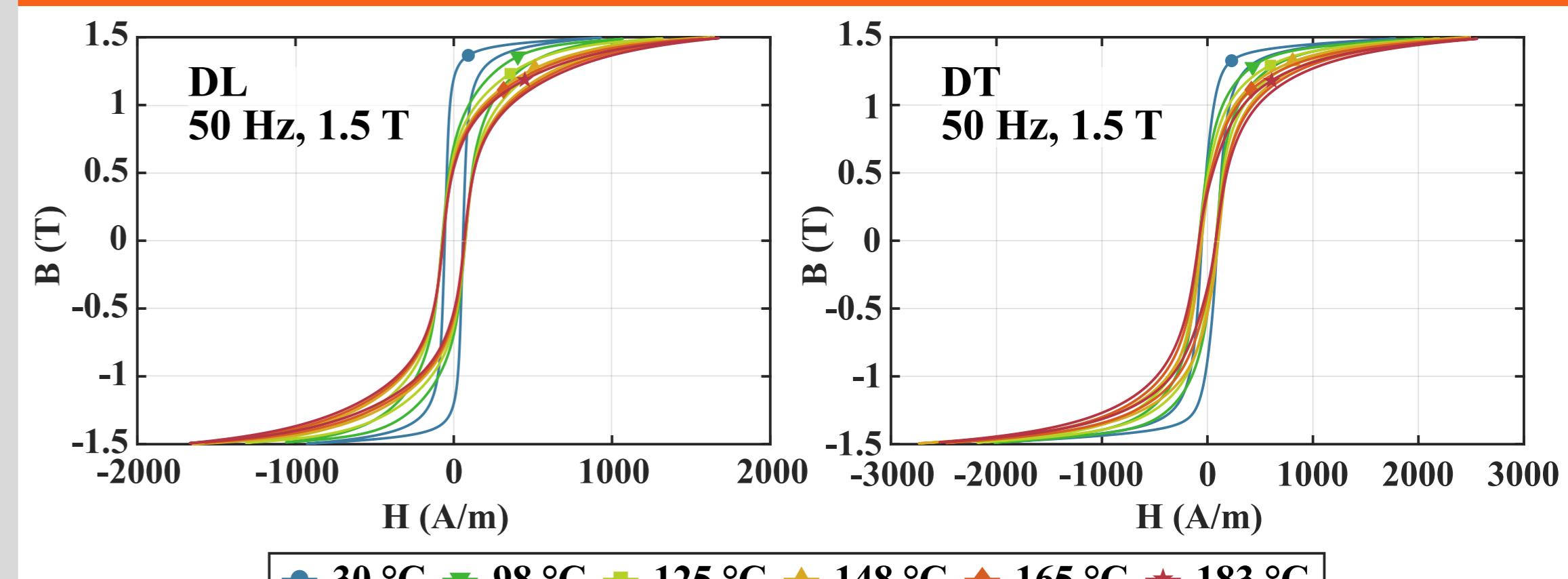
- The loci widen when the temperature increases
- This widening is proportionately stronger for low flux-density levels
- The increase is mostly apparent power, the energy is not dissipated

- The observed anisotropy of the loci decreases with increasing temperature
- H_{DL}/H_{DT} increases
- Rounder shapes for high temperatures



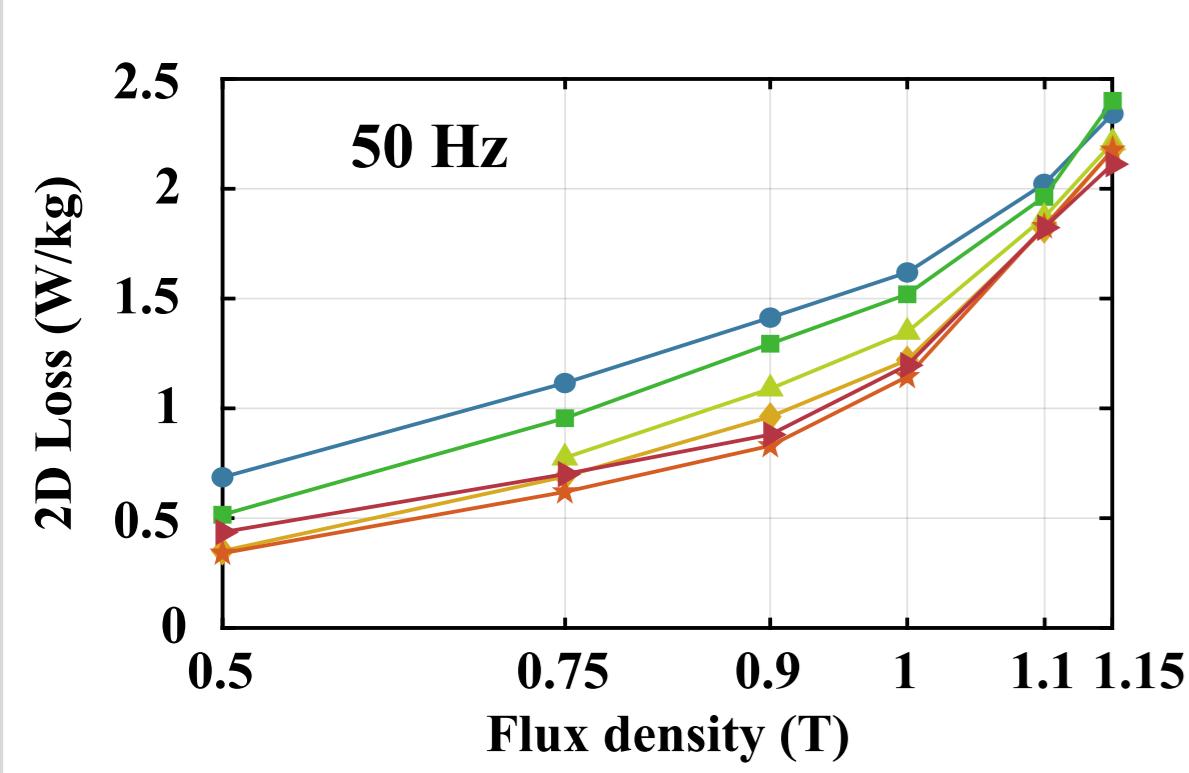
- For high flux densities :
 - Losses decrease with temperature
 - Reduction around [-10;-30]%
- For low flux density :
 - Loss variations are small (similar to repeatability error)
 - Losses at room temperature are noticeably lower than the others

4b. NO 1D



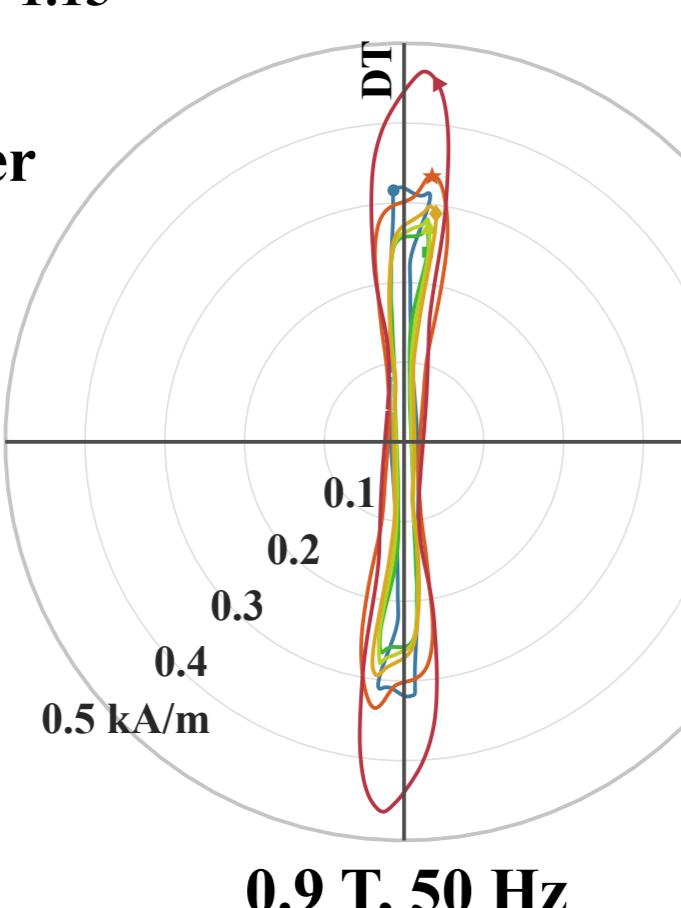
- The cycles evolution is coherent with the loci variations
- Peak H values along DL or DT vary at a similar rate between 1D & 2D
- Again noticeably lower loss at room temperature
- Compensated behaviours?
- Measurement problem?

5. GO 2D



- The loci widen with increasing temperatures
- Easy to see along the hard & medium directions
- Harder to evaluate along the easy direction (very low fields)

- Inconclusive behaviour of the observed anisotropy along temperature :
 - H_{DL}/H_{DT} increase along temperature
 - But H_{hard}/H_{DL} is non-monotonous



- Losses are mostly decreasing under increasing temperature
 - Especially between room temperature and 100 °C
 - Stronger decrease (under low flux densities) than for the NO, with [-20;-40]% reduction.
- Measurement precision to be assessed.

6. DISCUSSION

- Mostly expected behaviour for the non-oriented FeSi :
 - Anisotropy decreases with the raise in temperature: diminution of the anisotropy constant K (augmentation of the thermal agitation)
 - Overall decrease of the losses, due to lower conductivity and anisotropy
 - Why does the loss for low flux-density increase for mild temperatures...?
- Mixed results for the grain-oriented FeSi :
 - The variations of losses are more coherent (monotonously decreasing)
 - The evolution of the anisotropy shapes with temperature will need more analysis

7. PERSPECTIVES

Measurements

- 1D measurements vs T on GO
 - Along DL & DT
 - Along the hard direction ?
 - Loss decomposition
 - More frequencies needed

Materials

- Iron-Nickel
- Various & specific properties
- Including low Curie temperature
- Iron-Cobalt
- Close to motor applications